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U.S. PATENT APPLICATION

FOR

HEAD WITH THIN AFM WITH HIGH POSITIVE MAGNETOSTRICTIVE PINNED LAYER

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HEAD WITH THIN AFM WITH HIGH POSITIVE MAGNETOSTRICTIVE PINNED LAYER

FIELD OF THE INVENTION

The present invention relates to magnetic heads, and more particularly, this invention relates to read heads having magnetically pinned layers that stabilize the free layer.

BACKGROUND OF THE INVENTION

The heart of a computer is a magnetic disk drive which includes a rotating magnetic disk, a slider that has read and write heads, a suspension arm above the rotating disk and an actuator arm that swings the suspension arm to place the read and write heads over selected circular tracks on the rotating disk. The suspension arm biases the slider into contact with the surface of the disk when the disk is not rotating but, when the disk rotates, air is swirled by the rotating disk adjacent an air bearing surface (ABS) of the slider causing the slider to ride on an air bearing a slight distance from the surface of the rotating disk. When the slider rides on the air bearing the write and read heads are employed for writing magnetic impressions to and reading magnetic signal fields from the rotating disk. The read and write heads are connected to processing circuitry that operates according to a computer program to implement the writing and reading functions.

In high capacity disk drives, magnetoresistive (MR) read sensors, commonly referred to as MR heads, are the prevailing read sensors because of their capability to read data from a surface of a disk at greater track and linear densities than thin film inductive heads. An MR sensor detects a magnetic field through the change in the resistance of its MR sensing layer (also referred to as an "MR element") as a function of the strength and direction of the magnetic flux being sensed by the MR layer.

The conventional MR sensor operates on the basis of the anisotropic magnetoresistive (AMR) effect in which an MR element resistance varies as the square of the cosine of the angle between the magnetization in the MR element and the direction of sense current flow through the MR element. Recorded data can be read from a magnetic medium because the external magnetic field from the recorded magnetic medium (the signal field) causes a change in the direction of magnetization of the MR element, which in turn causes a change in resistance of the MR element and a corresponding change in the sensed current or voltage.

Another type of MR sensor is the giant magnetoresistance (GMR) sensor manifesting the GMR effect. In GMR sensors, the resistance of the GMR sensor varies as a function of the spin-dependent transmission of the conduction electrons between ferromagnetic layers separated by a non-magnetic layer (spacer) and the accompanying spin-dependent scattering which takes place at the interface of the ferromagnetic and non-magnetic layers and within the ferromagnetic layers.

GMR sensors using only two layers of ferromagnetic material (e.g., Ni-Fe) separated by a layer of non-magnetic material (e.g., copper) are generally referred to as spin valve (SV) sensors. In an SV sensor, one of the ferromagnetic layers, referred to as

the pinned layer (reference layer), has its magnetization typically pinned by exchange coupling with an antiferromagnetic (e.g., NiO or Fe-Mn) layer. The pinning field generated by the antiferromagnetic layer should be greater than demagnetizing fields (about 200 Oe) at the operating temperature of the SV sensor (about 120° C) to ensure that the magnetization direction of the pinned layer remains fixed during the application of external fields (e.g., fields from bits recorded on the disk). The magnetization of the other ferromagnetic layer, referred to as the free layer, however, is not fixed and is free to rotate in response to the field from the recorded magnetic medium (the signal field). U.S. Pat. No. 5,206,590 granted to Dieny et al., incorporated herein by reference, discloses a SV sensor operating on the basis of the GMR effect.

An exemplary high performance read head employs a spin valve sensor for sensing the magnetic signal fields from the rotating magnetic disk. FIG. **1A** shows a prior art SV sensor **100** comprising a free layer (free ferromagnetic layer) **110** separated from a pinned layer (pinned ferromagnetic layer) **120** by a non-magnetic, electrically-conducting spacer layer **115**. The magnetization of the pinned layer **120** is fixed by an antiferromagnetic (AFM) layer **130**.

FIG. **1B** shows another prior art SV sensor **150** with a flux keepered configuration. The SV sensor **150** is substantially identical to the SV sensor **100** shown in FIG. **1A** except for the addition of a keeper layer **152** formed of ferromagnetic material separated from the free layer **110** by a non-magnetic spacer layer **154**. The keeper layer **152** provides a flux closure path for the magnetic field from the pinned layer **120** resulting in reduced magnetostatic interaction of the pinned layer **120** with the free layer

110. U.S. Pat. No. 5,508,867 granted to Cain et al., incorporated herein by reference, discloses a SV sensor having a flux keepered configuration.

Another type of SV sensor is an antiparallel (AP)-pinned SV sensor. In AP-Pinned SV sensors, the pinned layer is a laminated structure of two ferromagnetic layers separated by a non-magnetic coupling layer such that the magnetizations of the two ferromagnetic layers are strongly coupled together antiferromagnetically in an antiparallel orientation. The AP-Pinned SV sensor provides improved exchange coupling of the antiferromagnetic (AFM) layer to the laminated pinned layer structure than is achieved with the pinned layer structure of the SV sensor of FIG. **1A**. This improved exchange coupling increases the stability of the AP-Pinned SV sensor at high temperatures which allows the use of corrosion resistant antiferromagnetic materials such as NiO for the AFM layer.

Referring to FIG. **2A**, an AP-Pinned SV sensor **200** comprises a free layer **210** separated from a laminated AP-pinned layer structure **220** by a nonmagnetic, electrically-conducting spacer layer **215**. The magnetization of the laminated AP-pinned layer structure **220** is fixed by an AFM layer **230**. The laminated AP-pinned layer structure **220** comprises a first ferromagnetic layer **226** and a second ferromagnetic layer **222** separated by an antiparallel coupling (APC) layer **224** of nonmagnetic material. The two ferromagnetic layers **226, 222** (FM_1 and FM_2) in the laminated AP-pinned layer structure **220** have their magnetization directions oriented antiparallel, as indicated by the arrows **227, 223** (arrows pointing out of and into the plane of the paper respectively).

A key requirement for optimal operation of an SV sensor is that the pinned layer should be magnetically saturated perpendicular to the air bearing surface. Lack of

magnetic saturation in the pinned layer leads to reduced signal or dynamic range. Factors leading to a loss of saturation include demagnetizing fields at the edge of the pinned layer, magnetic fields from recorded data and from longitudinal biasing regions, current induced fields and the coupling field to the free layer.

Analysis of the magnetic state of pinned layers in small sensors (a few microns or less in width), reveals that due primarily to the presence of large demagnetizing fields at the sensor edges the magnetization is not uniform over the area of the pinned layer. FIG. **2B** shows a perspective view of an SV sensor **250**. The SV sensor **250** is formed of a sensor stripe **260** having a front edge **270** at the ABS and extending away from the ABS to a rear edge **272**. Due to the large demagnetizing fields at the front edge **270** and the rear edge **272** of the sensor stripe **260**, the desired perpendicular magnetization direction is achieved only at the center portion **280** of the pinned layer stripe, while the magnetization tends to be curled into a direction parallel to the ABS at the edges of the stripe. The extent of these curled regions is controlled by the magnetic stiffness of the pinned layer.

Furthermore, prior art AP-Pinned SV sensors use an AFM in order to pin the pinned layer magnetization. Most commonly used AFM materials have blocking temperatures (temperature at which the pinning field reaches zero Oe) near 200° C. This means that if the temperature of the SV sensor approaches this temperature, the pinned layer magnetization can change its orientation resulting in degraded SV sensor performance.

Although AP-Pinned SV sensors have large effective pinning fields because near cancellation of the magnetic moments of the two sub-layers results in a low net magnetic

moment for the pinned layer, thermal stability is still a concern because the operating temperatures of these SV sensors in disk files can exceed 120° C. In addition, the AP-pinned layer structure is vulnerable to demagnetization during processing operations such as lapping.

Therefore there is a need for an SV sensor that increases the magnetic pinning of the pinned layer and reduces the sensitivity to demagnetizing fields particularly at the front and rear edges of the pinned layer stripe. In SV sensors that include AFM layers to provide exchange anisotropy fields to fix the pinned layer magnetization direction, there is a further need for an SV structure that reduces the temperature limitations imposed by the blocking temperature characteristics of the commonly used antiferromagnetic materials required in prior art SV sensors for providing pinning fields.

In any of the prior art sensors described above, the thickness of the spacer layer is chosen so that shunting of the sense current and a magnetic coupling between the free and pinned layer structures are minimized. This thickness is typically less than the mean free path of electrons conducted through the sensor. With this arrangement, a portion of the conduction electrons are scattered at the interfaces of the spacer layer with the pinned and free layer structures. When the magnetic moments of the pinned and free layer structures are parallel with respect to one another scattering is minimal and when their magnetic moments are antiparallel scattering is maximized. Changes in scattering changes the resistance of the spin valve sensor as a function of cos Θ, where Θ is the angle between the magnetic moments of the pinned and free layer structures. The sensitivity of the sensor is quantified as magnetoresistive coefficient dr/R where dr is the change in the resistance of the sensor as the magnetic moment of the free layer structure

rotates from a position parallel with respect to the magnetic moment of the pinned layer structure to an antiparallel position with respect thereto and R is the resistance of the sensor when the magnetic moments are parallel.

The transfer curve of a spin valve sensor is defined by the aforementioned cos Θ where Θ is the angle between the directions of the magnetic moments of the free and pinned layers. In a spin valve sensor subjected to positive and negative magnetic signal fields from a moving magnetic disk, which are typically chosen to be equal in magnitude, it is desirable that positive and negative changes in the resistance of the spin valve read head above and below a bias point on the transfer curve of the sensor be equal so that the positive and negative readback signals are equal. When the direction of the magnetic moment of the free layer is substantially parallel to the ABS and the direction of the magnetic moment of the pinned layer is perpendicular to the ABS in a quiescent state (no signal from the magnetic disk) the positive and negative readback signals should be equal when sensing positive and negative fields from the magnetic disk.

Accordingly, the bias point should be located midway between the top and bottom of the transfer curve. When the bias point is located below the midway point the spin valve sensor is negatively biased and has positive asymmetry and when the bias point is above the midway point the spin valve sensor is positively biased and has negative asymmetry. When the readback signals are asymmetrical, signal output and dynamic range of the sensor are reduced. Readback asymmetry is defined as:

$$\frac{V_1 - V_2}{\max(V_1 \text{ or } V_2)}$$

For example, +10% readback asymmetry means that the positive readback signal V_1 is 10% greater than it should be to obtain readback symmetry. 10% readback asymmetry is acceptable in some applications. +10% readback asymmetry may not be acceptable in applications where the applied field magnetizes the free layer close to saturation. The designer strives to improve asymmetry of the readback signals as much as practical with the goal being symmetry.

The location of the transfer curve relative to the bias point is influenced by four major forces on the free layer of a spin valve sensor, namely a ferromagnetic coupling field H_{FC} between the pinned layer and the free layer, a net demagnetizing (demag) field H_D from the pinned layer, a sense current field H_I from all conductive layers of the spin valve except the free layer, a net image current field H_{IM} from the first and second shield layers.

Another factor that can affect readback asymmetry is positive magnetostriction of the free layer structure. If the free layer structure has positive magnetostriction and is subjected to compressive stress, there will be a stress-induced anisotropy that urges the magnetic moment of the free layer from the aforementioned position parallel to the ABS toward a position perpendicular to the ABS. The result is readback asymmetry. The compressive stress occurs after the magnetic head is lapped at the ABS to form the stripe height of the sensor of the read head. After lapping, the free layer is in compression and this, in combination with positive magnetostriction, causes the aforementioned readback asymmetry. It is interesting to note that if the free layer structure has negative magnetostriction in combination with compressive stress that the magnetic moment of the free layer is strengthened along the position parallel to the ABS. A high negative

magnetostriction, however, is not desirable because it makes the magnetic moment of the free layer structure stiff and less responsive to field signals from the rotating magnetic disk. Accordingly, it is desirable that the magnetostriction of the free layer be zero or only slightly negative.

Unfortunately, magnetostriction of the free layer is difficult to control in present sputtering deposition systems. A typical free layer structure includes first and second free layers wherein the first free layer is cobalt iron and the second free layer is nickel iron with the first free layer interfacing the copper spacer layer for increasing the magnetoresistive coefficient dr/R of the sensor. Typical compositions of the free layers are cobalt iron ($Co_{90}Fe_{10}$) for the first free layer and nickel iron ($Ni_{83}Fe_{17}$) for the second free layer. When these layers are formed by sputter deposition the free layer structure invariably has an undesirable positive magnetostriction. In the past, the positive magnetostriction of the free layers has been accomplished by changing the composition of the free layers, such as reducing the iron content in the nickel iron and/or reducing the iron content in the cobalt iron. Since there is typically more than one nickel iron and cobalt iron layer in the spin valve sensor, this means that the targets in the sensor have to be changed in order to change the composition and lower the magnetostriction of the free layer structure.

In addition, new generations of heads must write to media having bit density of $\geq$200 Gbit/in^2. Heads that read and write to media with such high bit densities must have a very thin sensor stack. Some heads use AP pinned layers to stabilize the free layer. However, as the sensor stack is reduced, the pinned layers become more unstable. The magnetic orientations of the pinned layers of the sensor are set at manufacture. Under

certain conditions, be it high heat, stress, field, electrostatic discharge (spark), etc., the pinned layers can "flip flop," reversing their magnetic orientations. This immediately changes the polarity of the sensing signal to the opposite polarity. For example, if the polarity of the read signal is +1000 uV, the signal would be -1000 uV upon the magnetic orientations of the pinned layers flip-flopping. Usually, if the magnetic orientations of the pinned layers become flip-flopped, the damage is permanent and the head must be repaired (i.e., reset) or discarded. What is needed is a way to stabilize the pinned layers, preventing their magnetic orientations from flip-flopping.

SUMMARY OF THE INVENTION

The present invention overcomes the drawbacks and limitations described above by providing a magnetic head having a free layer, an antiferromagnetic layer spaced apart from the free layer, and an antiparallel (AP) pinned layer structure with a net magnetic moment equal to about zero positioned between the free layer and the antiferromagnetic layer. The AP pinned layer structure provides pinning through large magnetic anisotropy due to positive magnetostriction and small net moment for the antiparallel pinned layers. The antiferromagnetic layer provides a coercivity that enhances pinning of the AP pinned layer structure.

The magnetic orientations of the pinned layers are pinned by stress and magnetostriction, and the AFM layer adds coercivity to enhance the pinning, thereby reducing the probability that the magnetization of the pinned layers will flip to another orientation. This new structure provides good pinning of the pinned layer and prevents flipping of the magnetic orientations of the AP pinned layers.

In one embodiment, the antiferromagnetic layer provides a coercivity of at least about 300 Oe. Preferably, the antiferromagnetic layer provides a coercivity of at least about 400 Oe.

Preferably, the antiferromagnetic layer is constructed of PtMn having a thickness of between about 50 Å and 100 Å, and more preferably between about 60 Å and 90 Å. Also preferably, the antiferromagnetic layer has a high positive magnetostriction.

In another embodiment, the AP pinned layer structure includes at least two pinned layers having magnetic moments that are self-pinned antiparallel to each other, the pinned layers being separated by an AP coupling layer. Preferably, the AP pinned layer structure has a positive magnetostriction, the AP pinned layer structure having a magnetic anisotropy oriented perpendicular to an ABS of the reading head.

The reading head described herein may form part of a GMR head, a CPP GMR sensor, a CIP GMR sensor, a CPP tunnel valve sensor, etc. for use in a magnetic storage system. Preferably, the head is adapted to read from media having a bit density of at least about 200 $Gbit/in^2$.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantages of the present invention, as well as the preferred mode of use, reference should be made to the following detailed description read in conjunction with the accompanying drawings.

FIG. **1A** is an air bearing surface view, not to scale, of a prior art spin valve (SV) sensor.

FIG. **1B** is an air bearing surface view, not to scale, of a prior art keepered SV sensor.

FIG. **2A** is an air bearing surface view, not to scale, of a prior art AP-Pinned SV sensor.

FIG. **2B** is a perspective view, not to scale, of a prior art AP-Pinned SV sensor.

FIG. **3** is a simplified drawing of a magnetic recording disk drive system.

FIG. **4** is a partial view of the slider and a merged magnetic head.

FIG. **5** is a partial ABS view, not to scale, of the slider taken along plane **5-5** of FIG. **4** to show the read and write elements of the merged magnetic head.

FIG. **6** is an enlarged isometric illustration, not to scale, of the read head with a spin valve sensor.

FIG. **7** is an ABS illustration of a CPP GMR sensor, not to scale, according to an embodiment of the present invention.

FIG. **°** is an ABS illustration of a CPP tunnel valve sensor, not to scale, according to an embodiment of the present invention.

FIG. **9** is an ABS illustration of a CIP GMR sensor, not to scale, according to an embodiment of the present invention.

FIG. **10** is an ABS illustration of a CIP GMR sensor, not to scale, according to another embodiment of the present invention.

FIG. **11** is an ABS illustration of a CPP GMR sensor, not to scale, according to another embodiment of the present invention.

FIG. **12** is an ABS illustration of a CPP tunnel valve sensor, not to scale, according to another embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

The following description is the best embodiment presently contemplated for carrying out the present invention. This description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein.

Referring now to FIG. **3**, there is shown a disk drive **300** embodying the present invention. As shown in FIG. **3**, at least one rotatable magnetic disk **312** is supported on a spindle **314** and rotated by a disk drive motor **318**. The magnetic recording on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the disk **312**.

At least one slider **313** is positioned near the disk **312**, each slider **313** supporting one or more magnetic read/write heads **321**. More information regarding such heads **321** will be set forth hereinafter during reference to FIG. **4**. As the disks rotate, slider **313** is moved radially in and out over disk surface **322** so that heads **321** may access different tracks of the disk where desired data are recorded. Each slider **313** is attached to an actuator arm **319** by means way of a suspension **315**. The suspension **315** provides a slight spring force which biases slider **313** against the disk surface **322**. Each actuator arm **319** is attached to an actuator means **327**. The actuator means **327** as shown in FIG. **3** may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed magnetic field, the direction and speed of the coil movements being controlled by the motor current signals supplied by controller **329**.

During operation of the disk storage system, the rotation of disk **312** generates an air bearing between slider **313** and disk surface **322** which exerts an upward force or lift on the slider. The air bearing thus counter-balances the slight spring force of suspension **315** and supports slider **313** off and slightly above the disk surface by a small, substantially constant spacing during normal operation.

The various components of the disk storage system are controlled in operation by control signals generated by control unit **329**, such as access control signals and internal clock signals. Typically, control unit **329** comprises logic control circuits, storage means and a microprocessor. The control unit **329** generates control signals to control various system operations such as drive motor control signals on line **323** and head position and seek control signals on line **328**. The control signals on line **328** provide the desired current profiles to optimally move and position slider **313** to the desired data track on disk **312**. Read and write signals are communicated to and from read/write heads **321** by way of recording channel **325**.

The above description of a typical magnetic disk storage system, and the accompanying illustration of FIG. **3** are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuators, and each actuator may support a number of sliders.

FIG. **4** is a side cross-sectional elevation view of a merged magnetic head **400**, which includes a write head portion **402** and a read head portion **404**, the read head portion employing a dual spin valve sensor **406** of the present invention. FIG. **5** is an ABS view of FIG. **4**. The spin valve sensor **406** is sandwiched between nonmagnetic electrically insulative first and second read gap layers **408** and **410**, and the read gap

layers are sandwiched between ferromagnetic first and second shield layers **412** and **414**. In response to external magnetic fields, the resistance of the spin valve sensor **406** changes. A sense current (I_s) conducted through the sensor causes these resistance changes to be manifested as potential changes. These potential changes are then processed as readback signals by the processing circuitry **329** shown in FIG. **3**.

The write head portion **402** of the magnetic head **400** includes a coil layer **422** sandwiched between first and second insulation layers **416** and **418**. A third insulation layer **420** may be employed for planarizing the head to eliminate ripples in the second insulation layer caused by the coil layer **422**. The first, second and third insulation layers are referred to in the art as an "insulation stack". The coil layer **422** and the first, second and third insulation layers **416**, **418** and **420** are sandwiched between first and second pole piece layers **424** and **426**. The first and second pole piece layers **424** and **426** are magnetically coupled at a back gap **428** and have first and second pole tips **430** and **432** which are separated by a write gap layer **434** at the ABS. Since the second shield layer **414** and the first pole piece layer **424** are a common layer this head is known as a merged head. In a piggyback head an insulation layer is located between a second shield layer and a first pole piece layer. First and second solder connections (not shown) connect leads (not shown) from the spin valve sensor **406** to leads (not shown) on the slider **313** (FIG. **3**), and third and fourth solder connections (not shown) connect leads (not shown) from the coil **422** to leads (not shown) on the suspension.

FIG. **6** is an enlarged isometric ABS illustration of the read head **400** shown in FIG. **4**. The read head **400** includes the spin valve sensor **406**. First and second hard bias and lead layers **602** and **604** are connected to first and second side edges **606** and **608** of

the spin valve sensor. This connection is known in the art as a contiguous junction and is fully described in U.S. Pat. 5,018,037 which is incorporated by reference herein. The first hard bias and lead layers **602** include a first hard bias layer **610** and a first lead layer **612** and the second hard bias and lead layers **604** include a second hard bias layer **614** and a second lead layer **616**. The hard bias layers **610** and **614** cause magnetic fields to extend longitudinally through the spin valve sensor **406** for stabilizing the magnetic domains therein. The spin valve sensor **406** and the first and second hard bias and lead layers **602** and **604** are located between the nonmagnetic electrically insulative first and second read gap layers **408** and **410**. The first and second read gap layers **408** and **410** are, in turn, located between the ferromagnetic first and second shield layers **412** and **414**.

As mentioned above, heads that read from and write to media with high bit densities, e.g., $\geq$ about 200 Gbit/in^2, must have a very thin sensor stack in a direction perpendicular to the track width and height of the sensor. However, as the sensor stack is reduced, the AP pinned layers used to stabilize the pinned bias layer become more unstable resulting in "flip-flopping" or reversing of the magnetic orientations of the AP pinned layers upon exposure to high heat, stress, external fields, electrostatic discharge (spark), etc. Again, if the magnetic orientations of the pinned layers become flip-flopped, the damage is permanent and the head must be repaired (i.e., reset) or discarded.

The present invention provides a very thin sensor structure having a thin PtMn AFM layer and high positive magnetrostriction of AP-pinned layers with about a zero net magnetic moment for the pinned layer. The magnetic orientations of pinned layers are pinned by stress and magnetostriction, a net moment of the pinned layers is about zero, and the AFM layer adds coercivity to reduce the probability that the magnetization of the

pinned layers will flip to another orientation. This new structure provides enhanced pinning of the pinned layer and prevents flipping of the magnetic orientations of the AP pinned layers.

Many types of heads can use the structure described herein, and the structure is particularly adapted to a CPP GMR sensor, a CIP GMR sensor, and a CPP tunnel valve sensor. In the following description, the width of the layers (W) refers to the track width. The sensor height is in a direction into the face of the paper. Unless otherwise described, thicknesses of the individual layers are taken perpendicular to the plane of the associated layer and are provided by way of example only and may be larger and/or smaller than those listed.

CPP GMR

FIG. **7** depicts an ABS view of a CPP GMR sensor **700** according to one embodiment. "CPP" means that the sensing current (I_s) flows from one shield to the other shield in a direction perpendicular to the plane of the layers forming the sensor **700**.

As shown in FIG. **7**, a first shield layer (S1) **702** is formed on a substrate (not shown). The first shield layer **702** can be of any suitable material, such as permalloy (NiFe).

Seed layers are formed on the first shield layer **702**. The seed layers aid in creating the proper growth structure of the layers above them. Illustrative materials formed in a stack from the first shield layer **702** are a layer of Ta (SL1) **704**, a layer of NiFeCr (SL2) **706**, and a layer of NiFe (SL3) **70°**. Illustrative thicknesses of these materials are Ta (30Å), NiFeCr (20Å), and NiFe (8Å). Note that the stack of seed layers

can be varied, and layers may be added or omitted based on the desired processing parameters.

An AFM layer (AFM) **710** is formed above the seed layers. An AP pinned layer structure **712** is formed above the AFM layer **710**. The AFM layer **710** pins the AP pinned layer structure **712** to stabilize the AP pinned layer structure. The preferred material of the AFM layer **710** is PtMn. Normally, heads in this general configuration have a thick PtMn layer, i.e., >150Å, to achieve strong pinning of the pinned layers. However, this is too thick for sensors that read from media having a bit density of 200 Gbit/in^2 or higher. The preferred thickness of the AFM layer **710** is between about 50-100 Å, and more preferably between about 60-90 Å. The PtMn under the pinned layers gives rise to coercivity, and a thickness of 50-100 Å provides a coercivity of about 300 Oe or higher, and preferably about 400 Oe or higher. The high coercivity provided by the AFM layer **710** greatly increases the pinned strength of the pinned layer structure **712** over and above the self-pinning properties already inherent in the pinned layers described below, and tends to make the pinning permanent, thereby making the pinning more stable.

As shown in FIG. **7**, the pinned layer structure **712** includes first and second AP pinned magnetic layers, (AP1) and (AP2) **714**, **716**, are separated by a thin layer of an antiparallel coupling (APC) material **718** such that the magnetic moments of the AP pinned layers **714**, **716** are self-pinned antiparallel to each other. The pinned layers **714**, **716** have a property known as magnetostriction. The magnetostriction of the pinned layers **714**, **716** is very positive. The sensor **700** is also under compressive stresses because of its geometry at the ABS, and the configuration of the layer is such that it

produces very large compressive stress. The combination of positive magnetostriction and compressive stress causes the pinned layers **714, 716** to develop a magnetic anisotropy that is in a perpendicular direction to the track width. This magnetic coupling through the Ru spacer causes the pinned layers **714, 716** to have antiparallel-oriented magnetizations. The pinned layer structure in turn stabilizes the bias layer (described below) via exchange coupling.

In the embodiment shown in FIG. **7**, the preferred magnetic orientation of the pinned layers **714, 716** is for the first pinned layer **714**, into the face of the structure depicted (perpendicular to the ABS of the sensor **700**), and out of the face for the second pinned layer **716**. Illustrative materials for the pinned layers **714**, **716** are $CoFe_{10}$ (90% Co, 10% Fe), $CoFe_{50}$ (50% Co, 50% Fe), etc. separated by a Ru layer **718**. Illustrative thicknesses of the first and second pinned layers **714, 716** are between about 10Å and 25Å. The Ru layer **718** can be about 5-15Å, but is preferably selected to provide a pinned layer saturation field > 5 KOe, ideally about 10 KOe. In a preferred embodiment, each of the pinned layers **714, 716** is about 18Å to achieve about a zero net magnetic moment with an Ru layer **718** therebetween of about 8Å.

A first spacer layer (SP1) **720** is formed above the pinned layer structure **712**. Illustrative materials for the first spacer layer **720** include Cu, CuO_x, Cu/$CoFeO_x$/Cu stack, etc. The first spacer layer **720** can be about 10-30Å thick, preferably about 20Å.

A free layer (FL) **722** is formed above the first spacer layer **720**. The magnetic moment of the free layer **722** is soft and so is susceptible to reorientation from external magnetic forces, such as those exerted by data on disk media. The relative motion of magnetic orientation of the free layer **722** when affected by data bits on disk media

creates variations in the sensing current flowing through the sensor **700**, thereby creating the signal. Exemplary materials for the free layer **722** are CoFe/NiFe stack, etc. An illustrative thickness of the free layer **722** is about 10-40Å.

The magnetic orientation of the free layer **722** must be preset during manufacture, otherwise the orientation will be unstable and could move around at random, resulting in a "scrambled" or noisy signal. This instability is a fundamental property of soft materials, making them susceptible to any external magnetic perturbations. Thus, the magnetic orientation of the free layer **722** should be stabilized so that when its magnetic orientation moves, it consistently moves around in a systematical manner rather than a random manner. The magnetic orientation of the free layer **722** should also be stabilized so that it is less susceptible to reorientation, i.e., reversing.

An optional second spacer layer (SP2) **724** is formed above the free layer **722**. Illustrative materials for the second spacer layer **724** are Ta, Ru, Ta/Ru stack, Cu, etc. An exemplary thickness of the second spacer layer **724** is about 20-30Å.

An optional in-stack bias layer (BL) **726** is formed above the second spacer layer **724**. The magnetization of the bias layer **726** is pinned parallel to the track width, making the bias layer **726** act as a permanent magnet. The bias layer **726** stabilizes the free layer **722** through exchange coupling. This phenomenon is similar to the AP coupling of the pinned layers, except that the second spacer layer **724** must not be too thin or the free and bias layers may become permanently pinned and the head rendered practically ineffective.

Exemplary materials for the bias layer **726** are $NiFe_{10}$, CoNiNb, NiFeX (X = Cr, Mo, Rh, etc.), etc. An illustrative thickness of the bias layer **726** is about 10-40Å, and is

preferably selected such that it has a magnetic thickness comparable to the magnetic thickness of the free layer **722** to provide a flux closed structure, where the magnetic poles at the free layer edges are eliminated. Also note that where NiFe or NiFeX is used, the Ni/Fe ratio is preferably kept at about ≥90/10 to obtain a large negative magnetostriction, e.g., about $-2x10E^{-5}$. This magnetostriction together with compressive stress yields a Hk of greater than about 750 Oe at the bias layer, and preferably about 1000 Oe.

The thickness of the second spacer layer **724** is constructed such that the magnetic field created by the bias layer **726** enters the free layer **722**, stabilizing the magnetic orientation of the free layer **722**, preferably so that the magnetizations of the free and bias layers **722, 726** are antiparallel. Such thickness of the second spacer layer **724** in the exemplary embodiment shown in FIG. **7** is about 20-30Å thick. Also, a magnetic coupling is created between the free and bias layers **722**, **726** through the second spacer layer **724**, which enhances the stabilizing effect. Note that the magnetization of the free layer **722** remains soft in spite of the magnetic field of the bias layer **726**, thereby maintaining sufficient sensitivity necessary for reading magnetic media.

The magnetization of the bias layer **726** is preferably pinned parallel to the track width as opposed to perpendicular to the ABS. This can be accomplished by causing the bias layer **726** to have a negative magnetostriction by using other materials, such as those listed above, and preferably having a ≥90% Ni content. Further, Cr makes the material even more negative. When Nb is added, the material becomes amorphous (not crystalline), causing it to have a more negative magnetostriction. The negative magnetostriction in combination with large compressive stress (created by the geometry

of the layer) creates a magnetic anisotropy which is parallel to the track width W, which in turn causes the magnetic orientation of the bias layer **726** to be pinned parallel to the track width.

A cap (CAP) **728** is formed above the bias layer **726**. Exemplary materials for the cap **728** are Ta, Ta/Ru stack, etc. An illustrative thickness of the cap **728** is 20-30Å.

A second shield layer (S2) **730** is formed above the cap **728**.

CPP Tunnel Valve

FIG. **8** depicts an ABS view of a CPP tunnel valve sensor **800** according to one embodiment. The CPP tunnel valve sensor **800** generally has the same configuration as the structure shown in FIG. **7**, except that the first spacer layer **720** is formed of a dielectric barrier material, such as, Al_2O_3, AlO_x, MgO_x, etc. The first spacer layer **720** is very thin such that the electric current passing through the sensor **800** "tunnels" through the first spacer layer **720**. An illustrative thickness of the first spacer layer **720** is 3-6Å.

CIP GMR

FIG. **9** depicts an ABS view of a CIP GMR sensor **900** according to one embodiment. "CIP" means that the sensing current (I_s) flows from in a direction parallel to or "in" the plane of the layers forming the sensor **900**. The CIP GMR sensor **900** generally has the same configuration as the structures shown in FIGS. **7** and **8**, except that leads **902** of conventional materials and thicknesses are formed on opposite sides of the sensor **900** and the sensor **900** is sandwiched between an insulative material (G1), (G2) **904**, **906**. Another important difference is that current flows across the track width

as opposed to perpendicular to the track width. Because the current can flow through all of the layers, it is desirable to reduce the amount of current flowing through the bias layer **726** so that more current flows through the free layer **722**. To achieve this, an electrically resistive material can be selected to form the bias layer **726**. Preferably, the material selected to form the bias layer **726** is amorphous so that it has high resistivity. A preferred material is $(Co_{73}Ni_{12})_{85}Nb_{15}$. The material will also have a large magnetostriction, which causes the magnetic orientation of the bias layer **726** to be pinned parallel to the track width.

In all above embodiments a bias layer is used above the free layer separated by a spacer layer to stabilize the magnetic response of the free layer. One alternative approach to stabilize the free layer in all above embodiments is to use contiguous hard bias layers at the track edges of the sensor. As shown in FIG. **10**, for a CIP GMR sensor **1000**, these hard bias layers (HB) **1002** are in electrical contact with the sensor stack. In contrast, in the CPP GMR sensor **1100** shown in FIG. **11**, the hard bias layers (HB) **1102** are insulated from the sensor stack. FIG. **12** illustrates a CPP tunnel valve sensor **1200** with hard bias layers (HB) **1202** that are insulated from the sensor stack.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. For example, the structures and methodologies presented herein are generic in their application to all MR heads, AMR heads, GMR heads, spin valve heads, etc. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.